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Statistical analysis of mineralogical parameters used as lithostratigraphic markers. Application to Quaternary sediments of the littoral between Espinho and Furadouro (Portugal)

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ABSTRACT

The findings of lithological, sedimentological and mineralogical studies presented in this paper are based on samples from five boreholes located in the area surrounding the Aveiro Ria (northern Portugal), cores taken from depths of nearly 40 m. The sedimentary columns are constituted by fine and medium sands containing intercalations of silt and clay. A relative homogeneity was found in the mineralogical composition of the sedimentary columns. Nevertheless, there is some vertical variation with regards to the minerals that are better represented quantitatively (phyllosilicates, quartz and feldspars). Illite dominates in the clay fraction. However, both vermiculite and kaolinite can be found in significant amounts in some layers. Using the fine/coarse detrital minerals ratio and the vertical evolution of the factor scores (principal components analysis), a possible lithostratigraphic zonation was established, as well as a correlation between drilling cores. The result consisted of the definition of guide-layers, corresponding to clear anisotropies. We believe that the methodologies adopted could be of great interest in discriminating situations where the classical parameters yield homogenous information.

Key words: Statistical analysis, mineralogical parameters, lithostratigraphic markers, Quaternary sediments, Portugal.

RESUMEN

Análisis estadístico de parámetros mineralógicos usados como marcadores litoestratigráficos. Aplicación a sedimentos cuaternarios litorales entre Espinho y Furadouro (Portugal)

Se presentan los resultados correspondientes a los estudios litológicos, sedimentológicos y mineralógicos realizados en muestras provenientes de cinco sondeos efectuados en la región litoral circundante de la ría de Aveiro, que alcanzan profundidades en torno a los 40 m. Las columnas sedimentarias están constituidas por arenas de tamaño fino-medio, con intercalaciones finas de limos y arcillas. Se ha observado una relativa monotonía en la composición mineral a lo largo de las columnas, aunque con alguna variación vertical en lo referente a los minerales más abundantes (filosilicatos, cuarzo y feldespatos). En la fracción arcillosa, la ilita es el mineral predominante, junto con vermiculita y caolinita, que tienen una presencia relativamente importante en algunos niveles. Usando la razón entre minerales detríticos finos y gruesos y la evolución vertical de las factor scores *(análisis de componentes principales), se procedió a establecer la posible zonación litoestratigráfica y la correlación entre los sondeos. El resultado consistió en la definición de niveles guía, caracterizados por evidentes anisotropías en la evolución vertical de estos marcadores. Por último, creemos que son de gran interés estos tipos de metodologías en situaciones de evidente monotonía de los parámetros clásicamente utilizados, tales como la descripción litológica y las variaciones de composición mineral.*

Palabras clave: *Análisis estadístico, parámetros mineralógicos, marcadores litoestratigráficos, sedimentos cuaternarios, Portugal.*

INTRODUCTION

In the region surrounding the Aveiro Ria (northern Portugal), the Quaternary sediments were deposited in an estuarine environment characterised by low hydrodynamics. During an initial period characterised by a gradual sea retreat comprising advance and retreat stages, sandy deposits were developed, forming old beach platforms. Simultaneously, a drainage network was installed and fluvial terraces were formed. In historical times, a littoral sand spit was developed and the sandy littoral sedimentary environment changed to a confined silty/clayey anoxic environment, the present-day lagoon. Simultaneously, the eolic sands advanced towards the inland, originating a dunar mantle stabilised recently by vegetation.

The area of study is on the northern littoral of Portugal, demarcated by Paramos beach to the north and S. Pedro de Maceda beach to the south (figure 1). The area spreads over approximately 6 km, and detailed maps can be found on pages 13-A (Espinho) and 13-C (Ovar) of the Geologic Map of Portugal, scale 1:50 000.

The geologic maps of Ovar and Espinho for the area under study note the existence of: 1) Modern deposits including alluvium (a), beach sands and gravels as well dune sands (Ad); 2) Plio-Plistocene deposits of variable thickness and limits difficult to define; and 3) Xisto-Grauvaquico Complex.

The main objective of the present study was to collect data from which a better understanding of the morphoclimatic evolution of the region could be achieved.

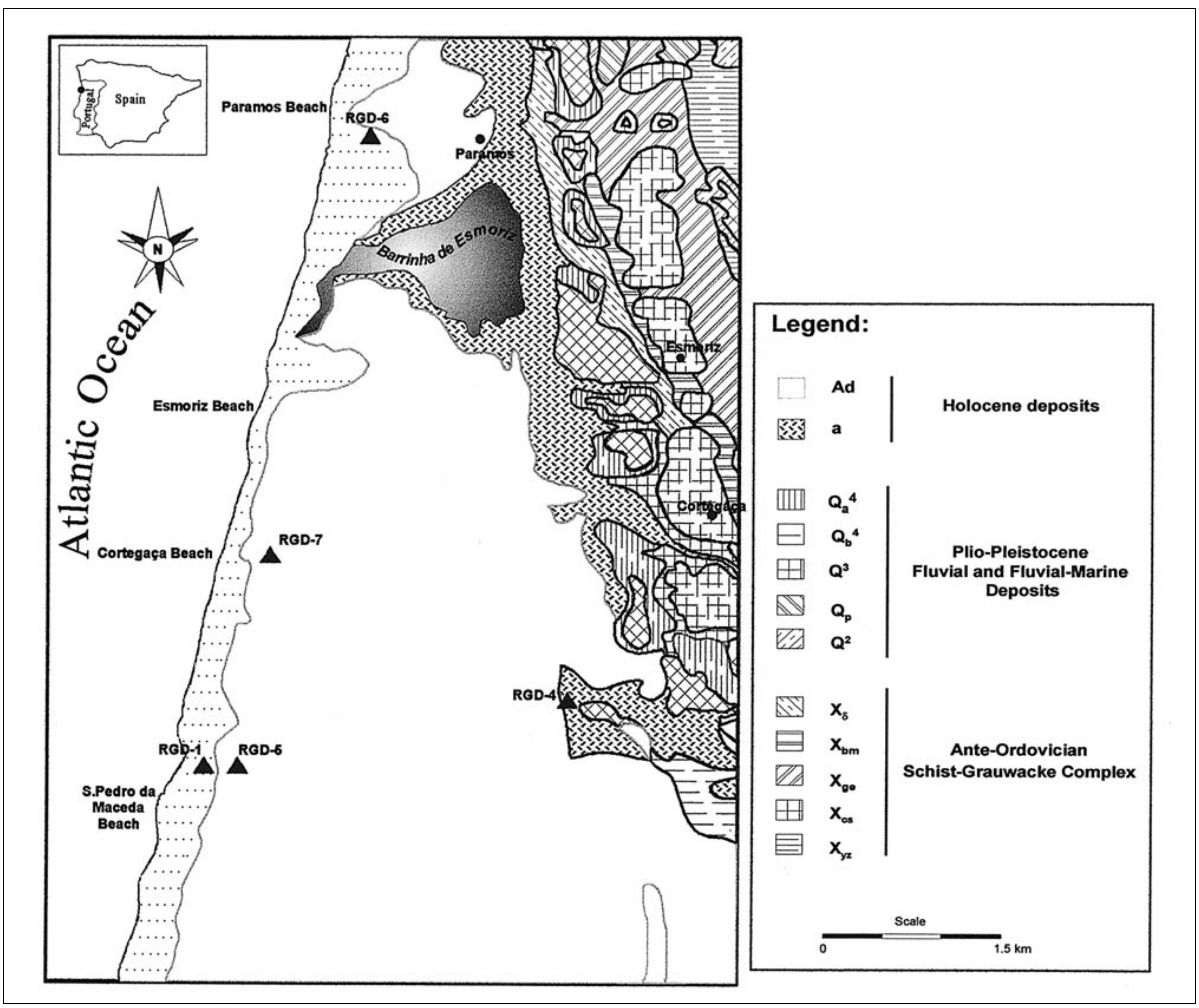

Figure 1. Location of the boreholes studied

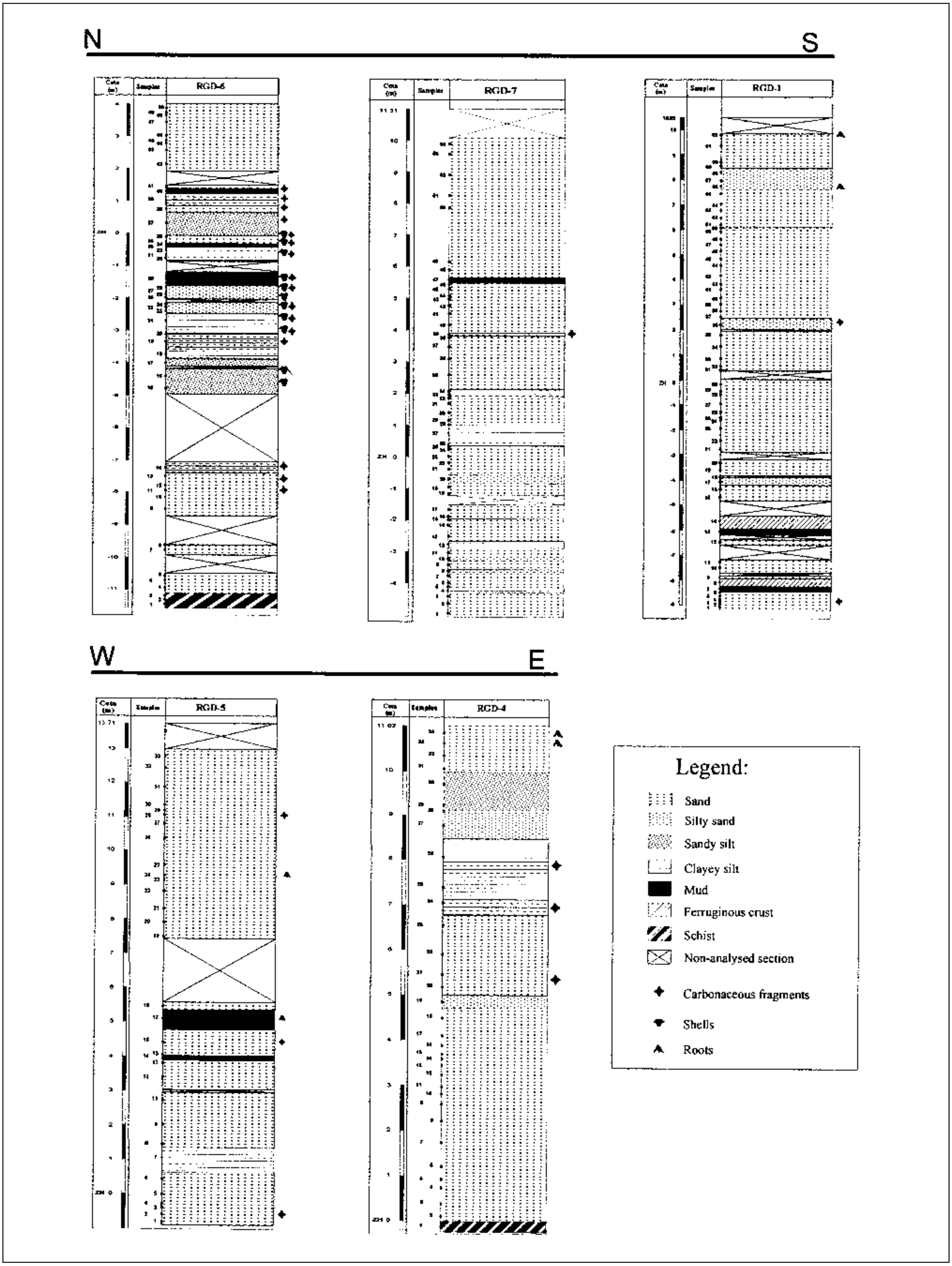

Figure 2. Lithostratigraphic logs of the boreholes studied

MATERIALS AND METHODS

In 1996, a well-drilling programme was carried out within the framework of a co-operative research project, involving teams from the Universities of Aveiro and Minho, among others. Seven boreholes, reaching average depths of 30-40 m, were drilled.

More than 250 samples, from five boreholes, were studied. Mineralogical studies were based mainly on Xray diffraction (XRD) determinations, carried out in both the < 38 µm and < 2 µm fractions (clay fraction).

For the semiquantitative determination of clay minerals, the criteria of Schultz (1964) and Thorez (1976) were used.

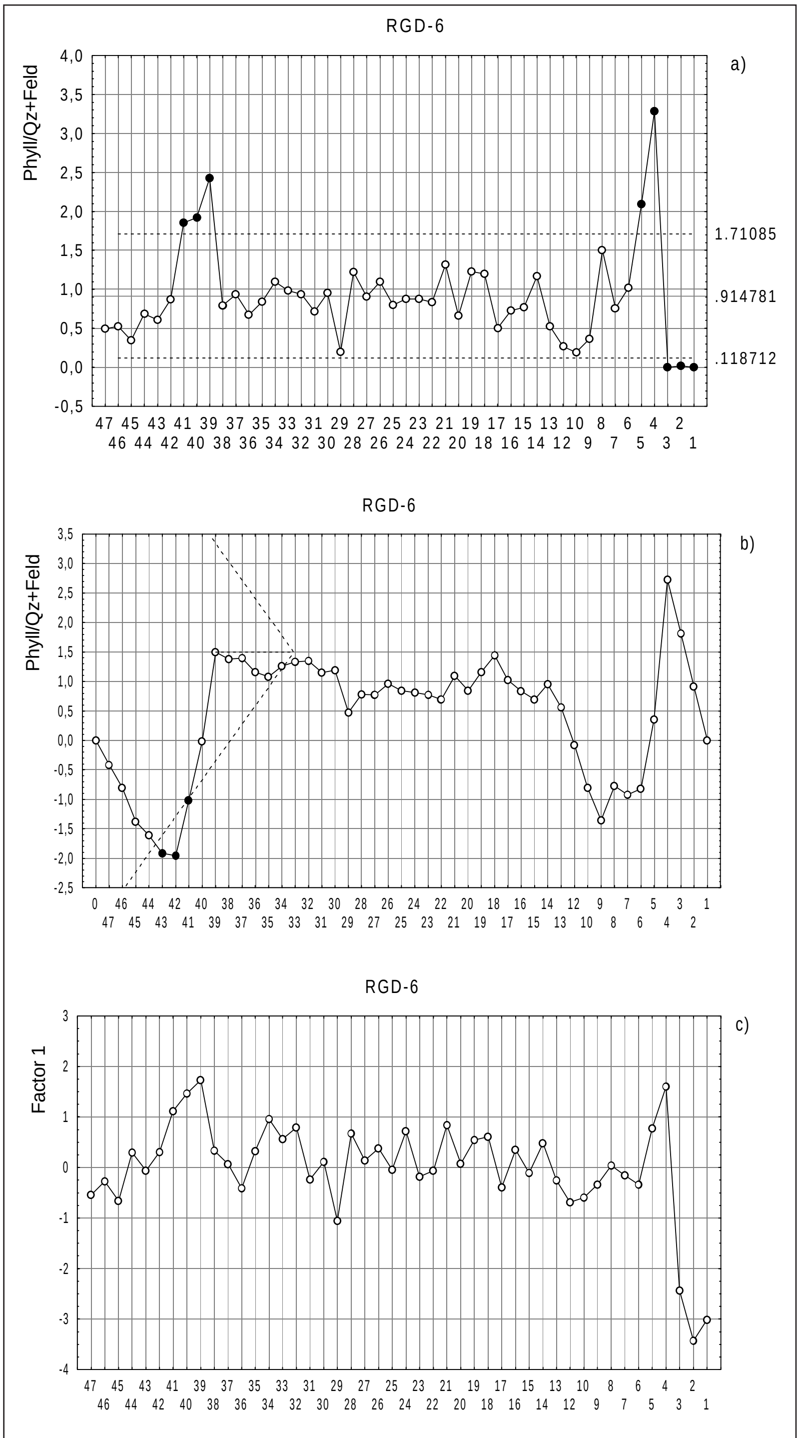

Figure 3. Vertical evolution of the parameters analysed, RGD 6 borehole: (a): phyllosilicates/quartz + feldspars, controlled by mean and standard deviation; (b): cumulative sum of deviations (of the same ratio); (c): factor scores (principal components analysis) of the mineralogic parameters

Quality control analysis (cumulative sum of deviations chart, or CUSUM, and X-bar chart) and multivariate factorial analysis of the mineralogical data were carried out.

On the CUSUM chart, if one plots the cumulative sum of deviations of successive sample means from a target specification, however minor, permanent shifts in the process mean will eventually lead to a sizeable cumulative sum of deviations. Thus, this chart is particularly well-suited for detecting such small, permanent shifts, which may go undetected when using the X-bar chart.

As López-Aguayo and González López (1995) have pointed out, use of multivariate factorial analysis statistical methods, as outlined by Imbrie and Van Andel (1964), Jöreskob, Klovan and

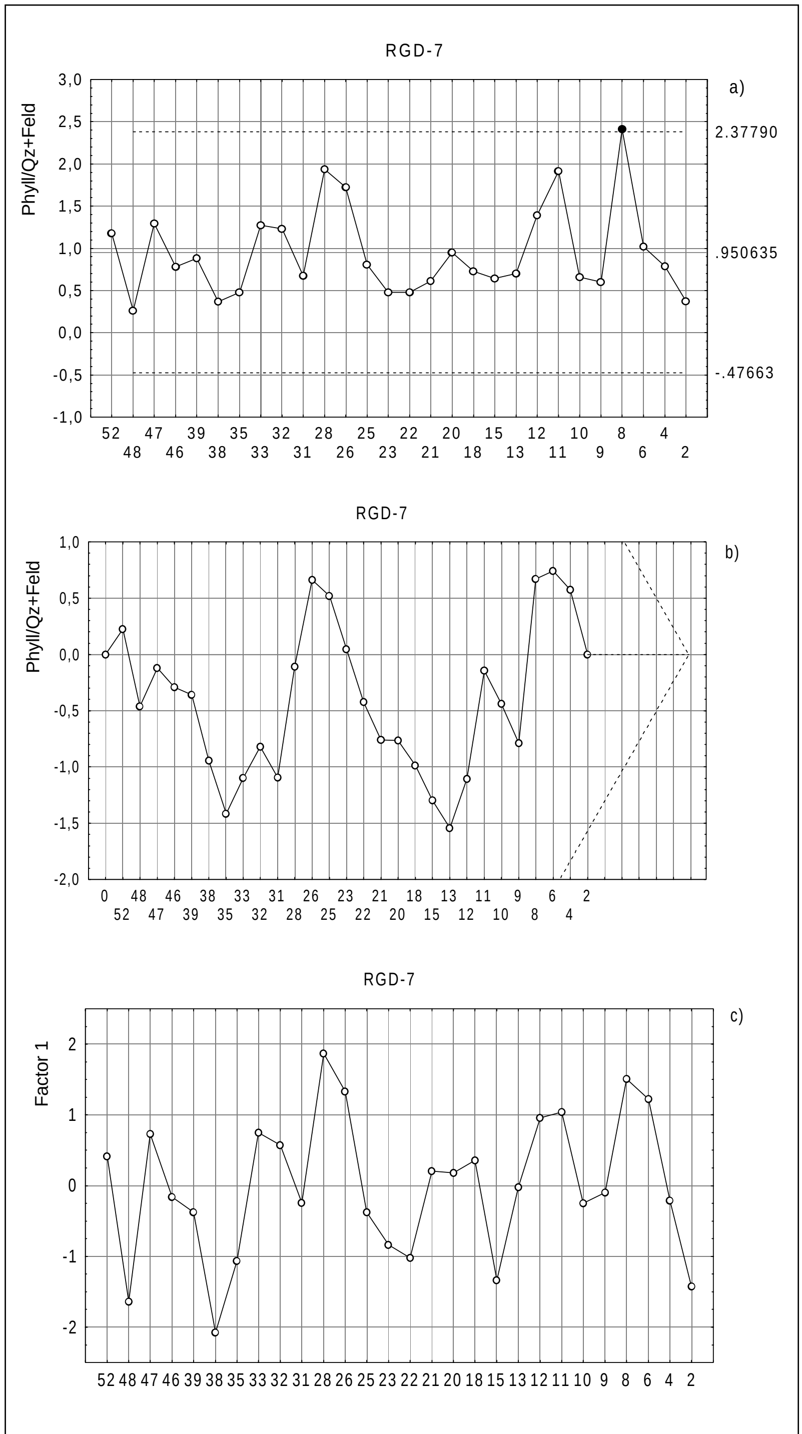

Figure 4. Vertical evolution of the parameters analysed, RGD 7 borehole: (a): phyllosilicates/quartz + feldspars, controlled by mean and standard deviation; (b): cumulative sum of deviations (of the same ratio); (c): factor scores (principal components analysis) of the mineralogic parameters

Reyment (1976), Davis (1986) and Reyment and Jöreskob (1993), enable us to make a good characterisation of the system data, reducing the complexity of the model and classifying the variables and samples into natural groups (Mezzadri and Saccani, 1989).

RESULTS

Figure 2 shows a synthesis of the lithological characteristics of the sedimentary columns of each borehole studied. Sediments consist of fine/medium sands, brownish to greyish, with some layers, in

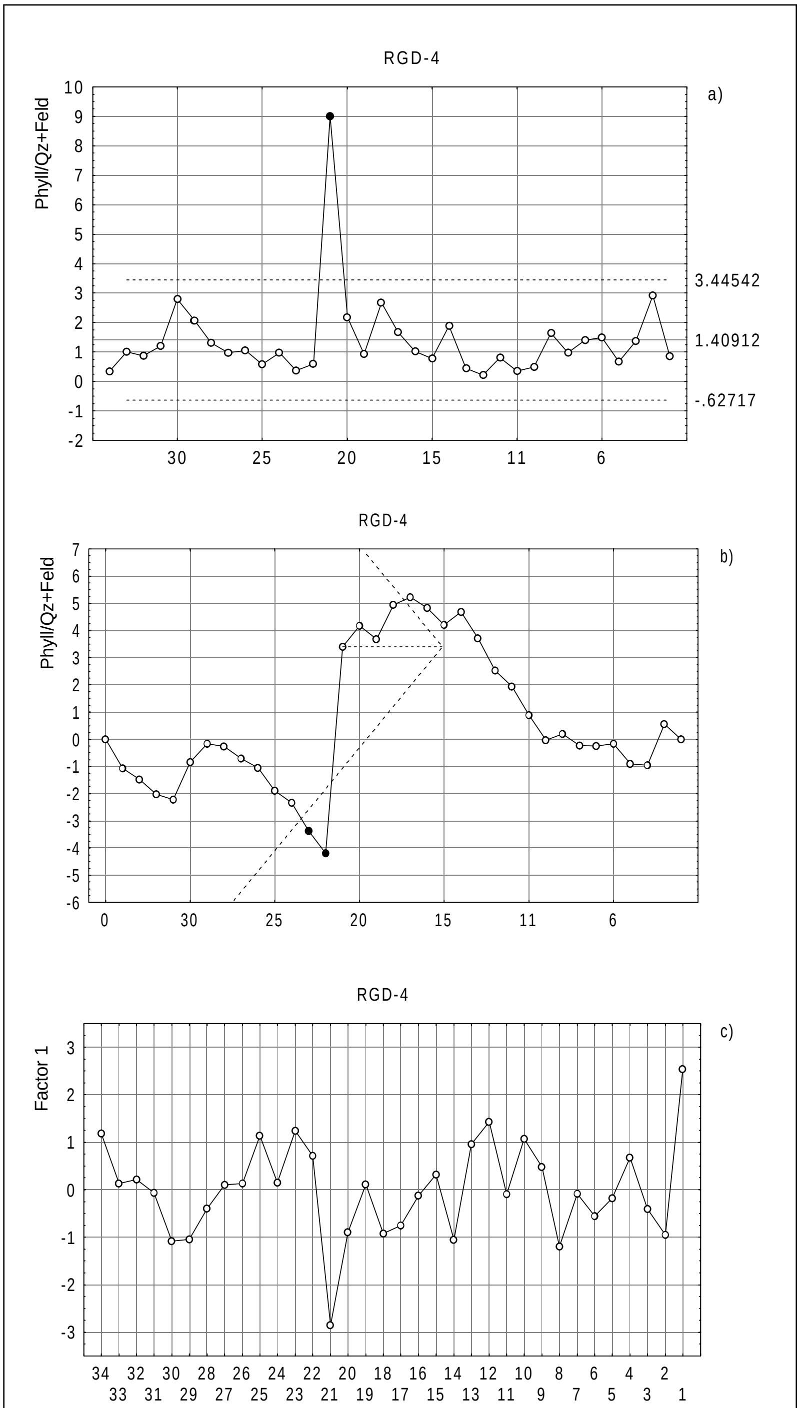

Figure 5. Vertical evolution of the parameters analysed, RGD 4 borehole: (a): phyllosilicates/quartz + feldspars, controlled by mean and standard deviation; (b): cumulative sum of deviations (of the same ratio); (c): factor scores (principal components analysis) of the mineralogic parameters

general very thin, of clays and muds, sometimes with shells. Two of the boreholes (RGD 4 and RGD 6) reached the regional bedrock, formed by schists and grauwackes.

The mineralogical composition of the < 38 µm fraction is very homogenous for all of he five studied boreholes' sedimentary columns. Quartz, phyllosilicates, K-Feldspar and Plagioclase are the more characteristics minerals of this fraction (< 38 µm), along with dolomite, gypsum and anhydrite (ubiquitous but always with a discrete presence) and, as accessory minerals, zeolites, opal C/CT, anatase,

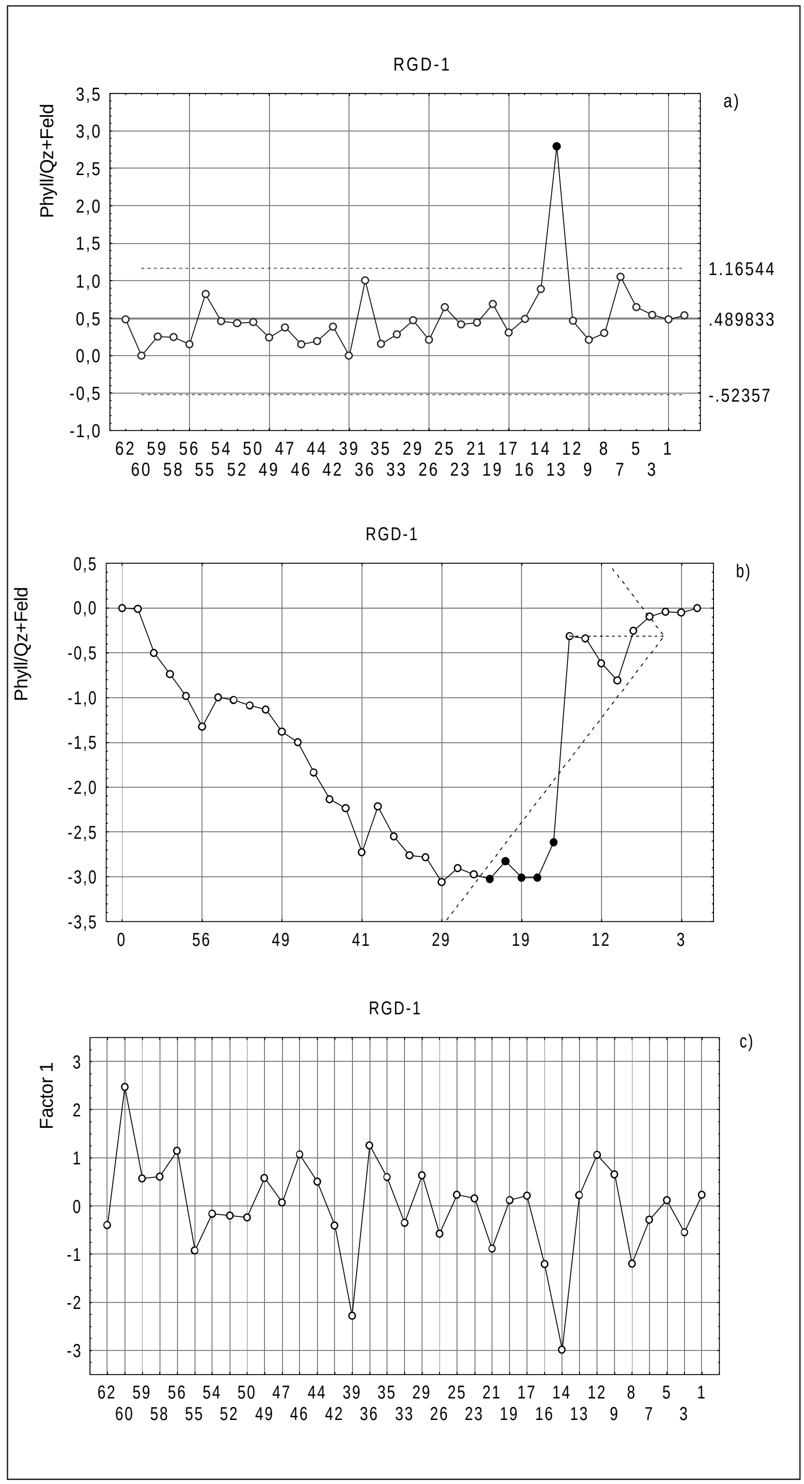

Figure 6. Vertical evolution of the parameters analysed, RGD 1 borehole: (a): phyllosilicates/quartz + feldspars, controlled by mean and standard deviation; (b) cumulative sum of deviations (of the same ratio); (c): factor scores (principal components analysis) of the mineralogic parameters

pyrite, marcassite, siderite, gibbsite, magnesite, calcite and halite.

As to the clay fraction (< 2 μm), illite is the predominant mineral, accompanied by kaolinite and vermiculite. In some layers, kaolinite and/or vermiculite show a relative increase in their presence. These clay minerals show, in general, low/medium crystallinity, with no significant vertical variation, in particular kaolinite and vermiculite. Illite shows a slightly higher crystallinity with a discrete vertical heterogeneity.

To establish a lithostratigraphic zonation in the sedimentary columns and to find eventual lateral correlations, mineralogical parameters were estab-

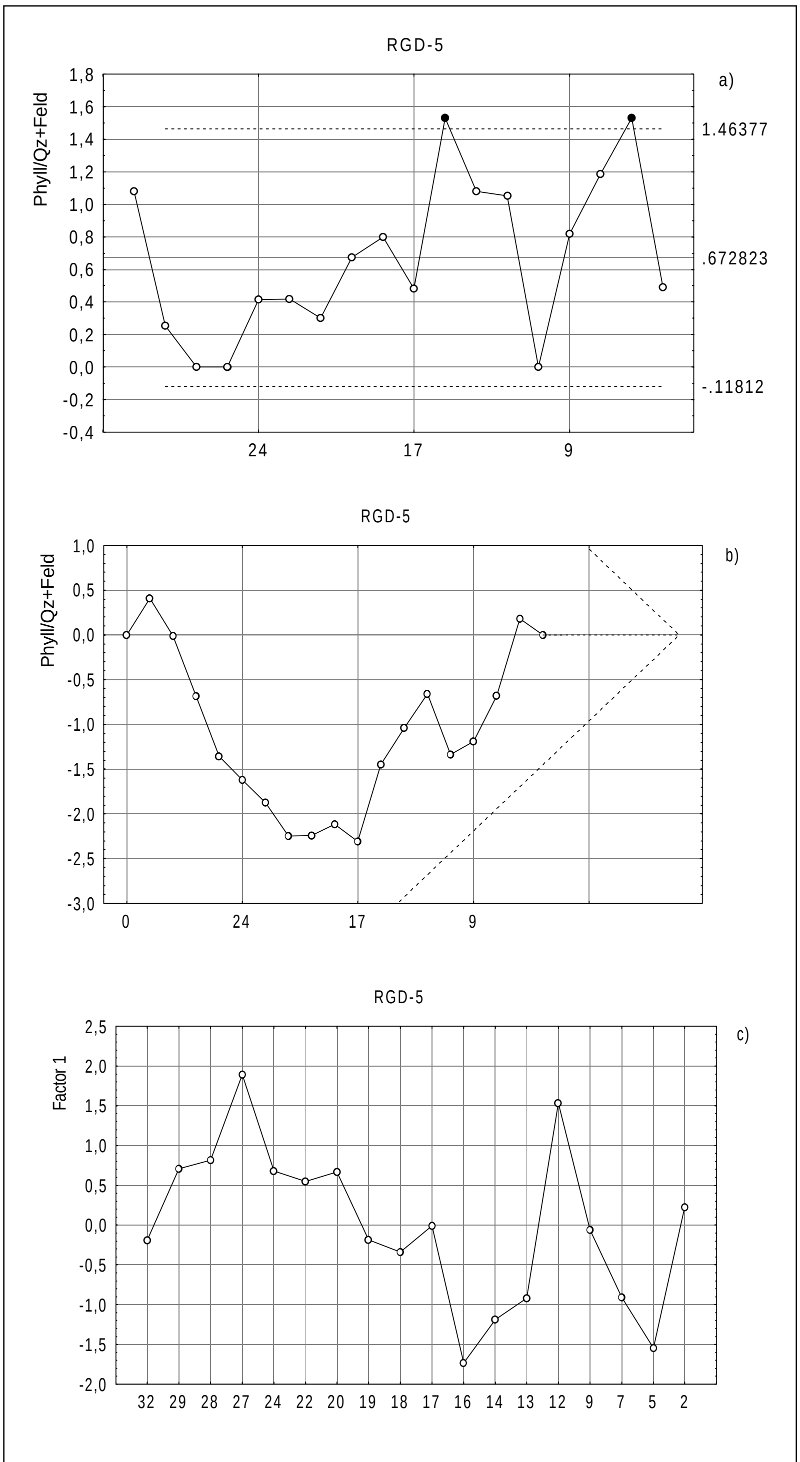

Figure 7 Vertical evolution of the parameters analysed, RGD 5 borehole: (a): phyllosilicates/quartz + feldspars, controlled by mean and standard deviation; (b): cumulative sum of deviations (of the same ratio); (c): factor scores (principal components analysis) of the mineralogic parameters

lished in order to define guide-layers. During the initial stage, we applied the phyllosilicates/ quartz+feldspars ratio, i.e. the fine detrital minerals/coarse detrital minerals ratio, submitted to statistical analysis, in particular quality control analysis (vertical evolution of the parameter controlled by mean and standard deviation –figures 3a, 4a, 5a, 6a and 7a– and vertical evolution of the cumulative sum of deviations –figures 3b, 4b, 5b, 6b and 7b).

As a second parameter, we applied the vertical evolution of the factor scores of the principal components analysis of the mineralogical parameters being quantified (figures 3c, 4c, 5c, 6c and 7c).

Analysing the vertical evolution of these parameters for the RGD 6 borehole (figure 3) we can see three anisotropies (represented by samples 12, 29 and 39), all very clear in any of the three graphs of the figure, but more evident in the one showing the cumulative sum of deviations (figure 3b). The second anisotropy is slightly less clear, meaning a minor variation of the mineral composition. The strong anisotropy present at the base of the three graphs (samples 1 to 4) is related to the bedrock schist and its weathering mantle.

Analysing the vertical evolution of the parameters studied for the RGD 7 borehole (figure 4) we can see four anisotropies (represented by samples 15, 26, 39 and 47), all very clear in any of the three graphs of the figure, in particular the second anisotropy, which is related to a finer, silty, layer, relatively richer in kaolinite.

Analysing the vertical evolution of the parameters studied for the RGD 4 borehole (figure 5) we can see three anisotropies (represented by samples 8, 21 and 29), all very clear in any of the three graphs of the figure, in particular the second anisotropy, which is related, once again, to a finer layer, relatively richer in kaolinite. The strong anisotropy present at the base of the three graphs (samples 1-3) is related to the bedrock schist and its weathering mantle, as in the previous case of borehole RGD 6.

Table I. Guide-layers, their lithologies and clay minerals composition. (I): illite; (K): kaolinite; (V): vermiculite; (C): chlorite

		RGD 6		RGD 7		RGD 4		RGD 1		RGD 5	
Units	Guide layers	Lithology	Mineralogy	Lithology	Mineralogy	Lithology	Mineralogy	Lithology	Mineralogy	Lithology	Mineralogy
V		Brownish Fine/ Medium sands	IKV Fine sands	Brownish	IKV Fine sands	Brownish	KIV Fine sands sands	Brownish	IKV Medium	Brownish	IKV
	D	Clayey silts	K	Clayey silts	K	Sandy silts	K	Medium sands	V	Medium sands	I
IV		Muds and silts with shells	IKV	Medium sands	IKV	Silty sands	VKI	Medium/ Fine sands	IKV	Silty sands	IKV
	C	Mudy silts with shells	I	Clayey silts	K	Brownish Sands	K	Brownish Sands	K	Greyish Sands	K
III		Silty sands with shells	IKV	Medium sands	KIV	Medium sands	IKV	Medium sands	IKV	Silty/ Medium sands	KIV
	B	Medium sands	KV	Micaceous silts with ferruginous materials	K	Brownish medium sands	K	Ferruginous crust	V	Medium sands	I
II		Coarser/ Medium sands	KIV	Medium sands	KIV	Brownish medium sands	IKV	Silty medium sands	IKV	Silty medium sands	KIV
	A			Silts	K			Ferruginous crust	K	Medium sands	K
I				Silty medium sands	KIV			Silty medium sands	IKV	Micaceous sands	KIV
Bedrock		Schist	IKC			Schist	IKC				

Analysing the vertical evolution of the parameters studied for the RGD 1 borehole (figure 6) we can see four anisotropies (represented by samples 17-8, 13-14, 36-39 and 55), all very clear in any of the three graphs of the figure, but more evident in the first (figure 6a) and third (figure 6c). Once again, the second anisotropy is slightly clearer, related, in this case, to a ferruginous crust.

Analysing the vertical evolution of the parameters studied for the RGD 4 borehole (figure 7), we can see four anisotropies (represented by samples 5, 12, 16 and 27), all very clear in any of the three graphs of the figure.

Therefore, the geostatistical analysis enabled us to define, in each of the five studied boreholes, 3-4 guide-layers (table I), characterised by clear anisotropies found in the vertical evolution of the selected parameters.

DISCUSSION

The utilisation of selected lithostratigraphic markers enabled us to define guide-layers in each of the five boreholes studied. These guide-layers were established on the basis of clear anisotropies found in the vertical evolution of certain mineralogical parameters.

Four guide-layers (A, B, C and D) could be defined. Guide-layer A was defined in the lower section of the sedimentary columns, guide-layers B and C were defined in the intermediate sections, and guide-layer D was defined in the upper section.

All four of these guide-layers are characterised by quantitative changes in the presence of kaolinite and/or vermiculite.

Therefore, we consider that the methodologies adopted could be of great interest in discriminating situations where the classical parameters yield homogenous information.

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